Resonant Reflectivity and Bragg Diffraction in Metal / Oxide Magnetic Multilayers

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Spin-polarized tunneling in thin multilayers alternating ferromagnetic (FM) and insulating (I) components (usually called magnetic tunnel junctions) are currently the focus of considerable interest in the field of artificially structured magnetic materials. These systems display large tunnel magnetoresistance (TMR) [1], that can be exploited in devices such as magnetic sensors, read heads for magnetic recording and non-volatile magnetic memories [2].

The overall magnetic behavior is controlled by several parameters, notably the spin polarization near the Fermi level of the conduction electrons in the metal, changes in the dielectric constant at interfaces, and interlayer magnetic coupling. The role of the ferromagnetic layer is obviously very important, since it acts as the source of spin polarized electrons. For this reason, ferromagnetic materials with a high spin polarization, such as Co, Fe or their alloys, are usually employed.

The *active layer* for the injection of polarized electrons through the insulating barrier is of very limited thickness and in contact with the insulator (Al_2O_3 in the present case). As a consequence, spin polarized tunneling will be strongly affected by structural and magnetic roughness, as well as by the oxidation of the active layer that might take place during the formation of the insulating barrier [3]. The characterization of the active layer requires an element selective and non-destructive technique, capable of probing the magnetism of buried layers in realistic structures (i.e. the ones expected to be used in devices).

In recent experiments performed at ALS, we have shown that the resonant magnetic scattering of circularly polarized soft x-rays (XRMS) can yield information about several interesting properties of magnetic multilayers [4]. X-ray scattering from a layered material is sensitive to changes in the optical constants along the normal to the layers. Since magnetic properties affect the optical constants at core excitations, resonant scattering of polarized x-rays can provide information about magnetic ordering of the layers, as well as about the magnetization depth profile within each layer of a given element.

We have started XRMS studies on metal/oxide magnetic structures using Co/Al_2O_3 and permalloy/Al_2O_3 multilayers as model systems. The samples were prepared by radiofrequency sputter deposition, and their characterization will be described elsewhere [5].

Measurements were performed at beamline 6.3.2 of the Advanced Light Source [6], using the high precision $\theta/2\theta$ high-vacuum reflectometer. The circular polarisation rate was set to 70 % by moving the vertical jaws defining the beam divergence accepted by the monochromator. The external magnetic field (1 kG) was applied along the intersection between the sample surface and the scattering plane using a permant magnet. The direction of the field was reversed at each acquisition point by rotating the magnet via a computer controlled in-vacuum stepper motor.

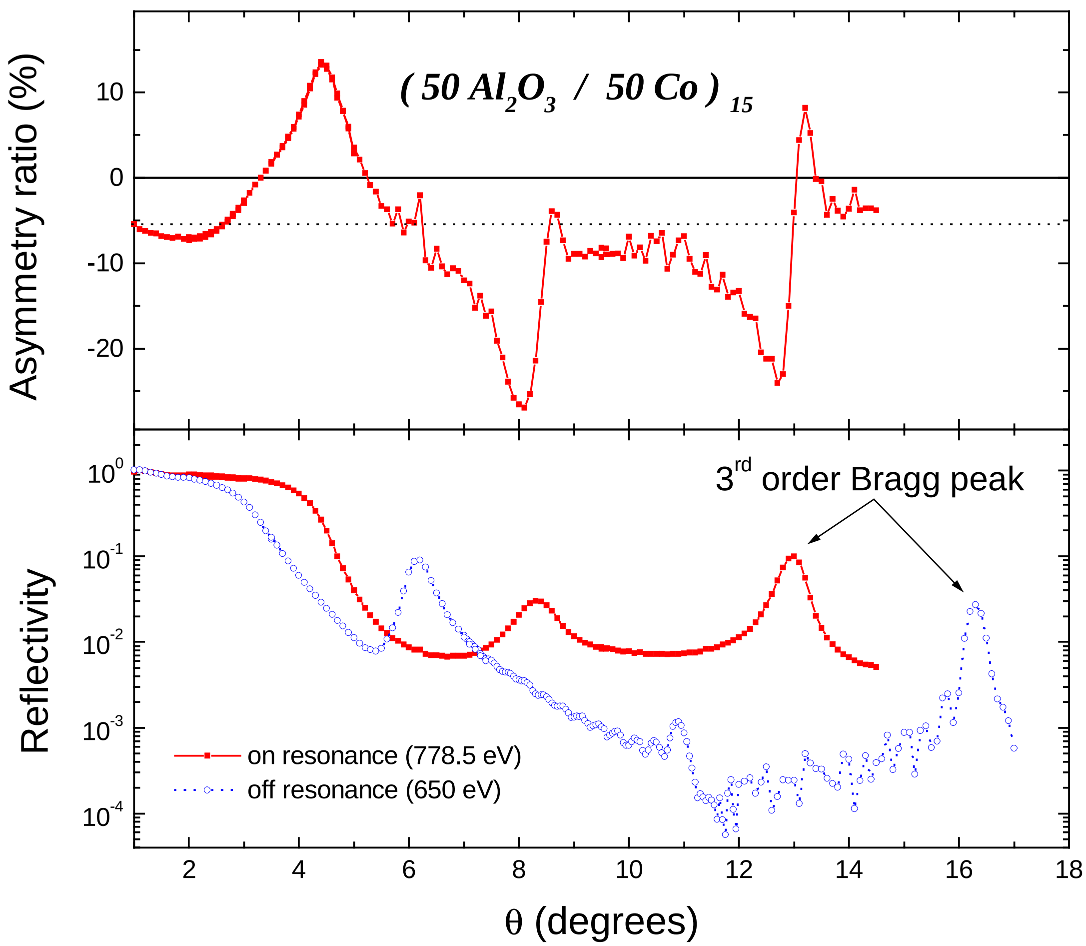

Figure 1. Magnetization averaged scattered intensity on a semilog scale (bottom) and magnetic asymmetry ratio (top) for a (50 Å Al_2O_3 / 50 Å Co)$_{15}$ multilayer. Filled squares refer to spectra collected for a photon energy corresponding to the Co L_3 absorption edge (on resonance), open circles to an energy of 650 eV (off resonance).

Fig. 1 shows the result of a θ/2θ scan on and off resonance for a (50 Å Al_2O_3 / 50 Å Co) multilayer of 15 periods grown on silicon. The resonant scattering spectrum is taken at a photon energy (778.5 eV) corresponding to the Co L_3 edge. The bottom panel reports the magnetization averaged scattered intensity, while the magnetic signal at resonance is shown in the top panel as the ratio between the difference and the sum of spectra obtained for opposite orientations of sample magnetization and photon helicity. The off resonance curve shows the Bragg peaks of 1st, 2nd and 3rd order related to the multilayer periodicicity. The corresponding d value is 101 Å, which agrees well with the nominal periodicity of 100 Å. Between the 1st and 2nd order Bragg peaks one can also observe the oscillations related to the total number of periods in the superstrucutre. At 778.5 eV, we observe a much higher scattered intensity (about 2 orders of magnitude above 12 degrees) coming from the resonant contribution to the charge scattering amplitude, which is weakly dependent on the angle over the measured range. At the same time, the strong absorption of the photons at the L_3 Co edge broadens the Bragg peaks and smears out the fine oscillations related to the number of periods. The top panel shows that large variations in the magnetic signal occurs under Bragg conditions. The observed oscillations versus angle do not lie either side of a zero value, but rather a line shifted by - 6 % (thin dotted line). This is due to the fact that at resonance the scattering amplitude of the elliptically polarised photons is affected by the term $(\mathbf{e}_f^* \times \mathbf{e}_i) \cdot \mathbf{m}\ (F_{+1} - F_{-1})$, where $\mathbf{e}_i$ and $\mathbf{e}_f$ are the polarization vectors of the incoming and outgoing photons, **m** is the unit vector in the direction of the magnetization, and $(F_{+1} - F_{-1})$ is related to circular magnetic dichroism in absorption.

In general, working under resonant Bragg conditions enhances the magnitude of the magnetic effects. This can be very important when one wants to use the dichroism on the scattered intensity as a measure of magnetization related properties, such as drawing element specific hysteresis curves, imaging magnetic domains, or defining critical values of temperature and applied magnetic field. For such applications, the sensitivity is directly related to the maximum observable magnetic contrast. Fig. 2 shows the result of an energy scan at the Co 2p edges for a scattering angle that fulfills resonant Bragg conditions for the (50 Å Al_2O_3 / 50 Å Co) multilayer: an asymmetry ratio in excess of 60 % is observed at 776.4 eV, meaning that a change by a factor of four in the scattered intensity is obtained upon magnetization reversal.

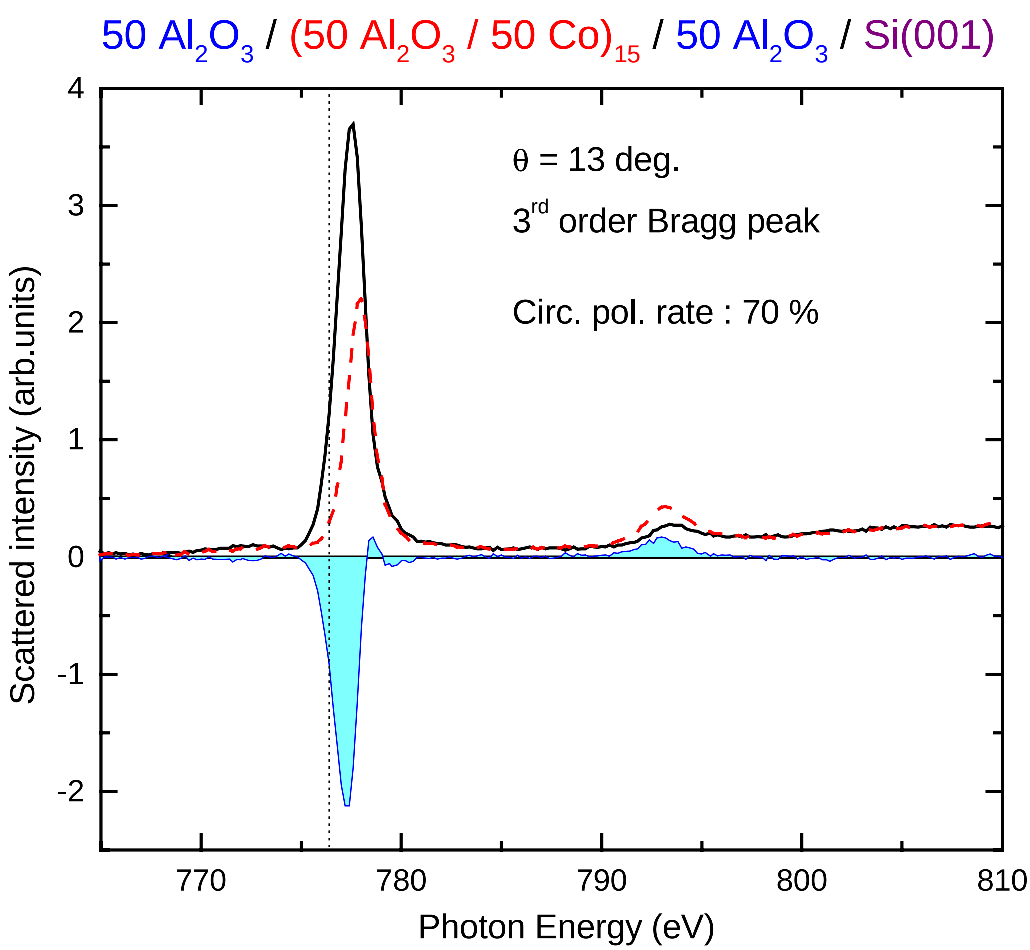

Figure 2. Scattered intensity over the photon energy range including the Co 2p edges, for a grazing angle of 13 degrees satisfying resonant Bragg conditions. The vertical dotted line indicates the photon energy giving an asymmetry ratio in excess of 60%

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